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The Development and Application of Water Management Sustainability Indicators in Brazil and Scotland

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The Development and Application of Water Management Sustainability Indicators in Brazil and Scotland

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Abstract: This paper reports the formulation and application of a framework of catchment-level water resource management indicators designed to integrate environmental, economic and social aspects of sustainability. The framework of nine indicators was applied to the R. Dee and R. Sinos catchments in Scotland and Brazil, respectively, following an indicator selection process that involved inputs from water management professionals in both countries, and a pilot exercise in Scotland. The framework was found to capture a number of key sustainability concerns, and was broadly welcomed by water resource managers and experts as a means of better understanding sustainable water resource management. Issues relating to poor water quality and public water supply were particularly prominent in the findings for the Sinos, while findings for the Dee suggested that more attention might be focused on building institutional capacity and public participation in catchment management. The use of some proxy indicators was required in both catchments due to poor data availability, and this problem may hinder the further development of indicator frameworks that attempt to better integrate environmental, economic and social dimensions of sustainability.

Keywords: sustainability, indicators; water management; catchment management; River Dee; River Sinos

1. Introduction

The continued destruction of ecosystems, loss of aquatic species, dislocation of human populations, inundation of cultural sites, disruption of sedimentation processes, and contamination of water sources (e.g. Falkenmark, 1998; Gleick, 2000; World Resources Institute, 2003; Sophocleous, 2004) are all evidence of the over-exploitation and poor management of freshwater resources. The concept of sustainable development, however, has reinvigorated attempts to better manage the water environment through appropriate policy-making and planning strategies, and represents an important extension of the principles of integrated water management (Simonovic, 1996). According to the OECD (2003: 19), "water is the perfect example of a sustainable development challenge – encompassing environmental, economic and social dimensions." The sustainable management of water resources, therefore, implies not only the indefinite continuation of physically and biologically stable systems (Newson *et al*., 2000), but also concern for the other dimensions of sustainable development, such as the economic efficiency of water use, the equitable distribution of the costs and benefits of water resource developments, and participatory approaches to policy-making and decision-taking (Lee, 1992, Stagl, 2004).

The 'science of sustainability' (O'Riordan, 2004) compounds the complexities of understanding hydrological processes by also requiring both a dynamic view of water resources management as a continuous learning process rather than an end-point (Kay, 2000), and an holistic and integrated appreciation of the interplay between environmental, economic and social dimensions of sustainability. A broad understanding of sustainability in the context of water resources must draw on both objective science and qualitative judgements on progress. Not surprisingly, therefore, sustainable water resources management is, to some extent, an elusive and contested notion (Rydin, 1999). This said, conceptual difficulties may be overcome by 'learning from doing'; i.e. by attempting to translate the goals of sustainable development into practical management approaches, and there is a clear need to operationalize sustainability principles using appropriate systems of assessment (e.g. Hardi and Zedan, 1997, O'Riordan, 2002, Starkl and Bruneer, 2004).

Assessing the sustainability of water resources management requires appropriate frameworks of indicators, which can, ideally, describe and communicate current (and, perhaps, previous) conditions, foster critical thinking about remedial actions required, and facilitate the participation of various stakeholders in decision-making processes (Brugmann, 1997). Bossel (1999) argues that indicators should provide essential information on the viability of a system and its rate of change, and on how these contribute to the sustainable development of the overall system. They should interconnect environmental and social dimensions (Levett, 1998), and also offer a ‘social learning’ capability, particularly learning from policy initiatives (Hezri, 2004). It is important to appreciate, however, that in choosing indicators, and even in interpreting findings from their application, value judgements are inevitable (Levett, 1998). Nevertheless, Bell and Morse (2003) suggest that a ‘good’ indicator is (ideally): specific (must clearly relate to outcomes); measurable (must be quantifiable); usable (practical); sensitive (must readily change as circumstances change); available (relatively straightforward to collect the necessary data); and, cost-effective (should not be a very expensive task to access the necessary data).

Experience is still limited, but previous work on the development and application of sustainable development indicators for water resources management has been reported in the literature. Although valuable, a number of limitations are generally apparent in this work. A common limitation is the focus on biophysical aspects of sustainability, often to the exclusion of socio-economic factors that may, in fact, frequently be the driving force behind environmental change (e.g. Kondratyev *et al.*, 2002). There are also proposed frameworks that rely on data not commonly available, and that may, perhaps, be too complex to allow findings to be communicated to a wide audience of stakeholders (e.g. Walmsley, 2002). Approaches that aggregate all sustainability aspects into a single index (e.g. Aguirre-Muñoz *et al.*, 2001) may obscure important insights into individual sustainability parameters. Other attempts may avoid such difficulties, but do not lend themselves to application at the river catchment level (e.g. Hellström *et al.*, 2000), recommended as the most appropriate scale for the management of freshwater systems (Jones, 1997; Aspinall and Pearson, 2000).

Recognising these limitations, the research reported here sought to develop a framework of water sustainability indicators for the catchment scale that integrated socio-economic and environmental dimensions, and that could assist policy-making and the wider communication and understanding of water resource issues. Research objectives were to: (1) develop an appropriate framework of indicators; (2) apply the framework to contrasting catchment situations; and, (3) provide an initial evaluation of the framework of indicators. This paper describes the indicator development process and the application of the framework to catchments in Brazil and Scotland.

Local water management professionals and experts were involved in the design and evaluation of the indicator framework in an attempt to enhance its practical benefits.

2. Method

This section details the methodological approaches adopted in the research, structured to follow the research objectives provided above.

2.1. Developing the indicator framework

The process of developing the indicator framework combined information gathering from a number of different sources, informed judgements by the researchers and others, and a pilot exercise conducted in Scotland. This interactive and inductive approach also involved key water management professionals and specialists in choosing and refining indicators. The final nine chosen indicators are described in Table 1. A summary of their development and selection is provided below.

Initially, some 50 water sustainability criteria were selected for further development based upon a review of the relevant international literature and policy documentation. Corresponding indicator expressions, normally with alternatives, were then formulated for each criterion. In order to reduce the number of indicators to a more manageable number, a further process of selection was undertaken. This involved semi-structured interviews with water resource experts and local (catchment) water management professionals in both Brazil and Scotland (see Table 2; note that only job titles were provided in order to maintain the anonymity of respondents). These individuals also provided important insights into local water management issues, further sources of water policy information, and data availability for indicators. The process of indicator refinement was also informed by a perceived need on the part of the researchers to include an equal number of broadly ‘economic’, ‘environmental’ and ‘social’ indicators in the framework in an attempt to address the three key aspects of sustainable development in a balanced manner.

Using a preliminary set of indicators, a pilot exercise was conducted for the R. Don catchment in north-east Scotland. This was designed to be as realistic as possible, and involved the acquisition and analysis of data (where possible) from governmental and academic organisations. Following the pilot exercise, and in the light of further discussions with water management professionals, further adjustments to the indicators were made. In particular, a preliminary indicator relating to soil conservation was replaced by an indicator of hydrological flow variability, and several indicator expressions were simplified in an attempt to lessen problems associated with data availability. It is important to acknowledge that the development and use of sustainability indicators involve considerable subjectivity and reflexivity. The criteria involved in the selection of indicators were imposed by both the researchers and the interviewees, as summarised in Table 3.

The final framework of indicators (Table 1) attempts to address, combine or relate the different economic, environmental and social aspects of sustainable water resources management, and, as such, requires a mix of quantitative and qualitative data. Two indicators in particular rely on quantitative and qualitative data, namely institutional preparedness and public participation. For those two the assessment involves a check-list and subsequent scoring, which allow the transformation of qualitative data into numerically quantifiable results. As far as we can ascertain, the great majority of individual indicator expressions have not previously been used or reported in the literature. The development and selection of indicators is a subjective process (Grunwald, 2004), and the work reported here is no exception. Clearly, for example, a trade-off was involved in developing the indicators: ease of use of the indicator framework (requiring relatively few indicator expressions) against the complexity of incorporating every potentially relevant aspect of catchment functioning and management.

By way of brief justification for the final choice of individual indicator expressions, the main determinants of environmental sustainability (interpreted as the long-term stability and viability of natural processes within the catchment) were deemed to be the maintenance of good water quality and adequate water flows, and the apparent stability of flow to external pressure (Table 1). Economic indicators were designed to reflect the function of water in providing (non-declining) benefits to users over time. Understanding how efficiently water is used, the demands exerted by various sectors, and the preparedness of local institutions to manage change and conflict in allocating water use were, therefore, deemed to be of fundamental importance. Indicators of the social dimension of sustainability were designed to capture the extent to which local people have access to the benefits of water supply, and are involved in decision-making processes affecting water management. Where appropriate, indicators were designed to allow local thresholds (e.g. for water quality) to be incorporated into the indicator expression.

2.2. Applying the indicator framework

The indicator framework was applied to the R. Dee catchment in Scotland and the R. Sinos catchment in Brazil. These countries have contrasting water development and management issues, allowing the framework to be applied in different historical and geographical contexts. This said, catchment choice was also informed by the knowledge and experience of the researchers; in particular, the likely availability of data from a variety of organisations and institutions, and the existence of appropriate water management agencies and structures able to respond to local water management issues. A summary of selected catchment characteristics is provided in Table 4.

The calculation of indicator values required the collection, manipulation and analysis of data from a variety of secondary sources, including water company/authority records, environmental databases, and government reports and other publications. Both quantitative and qualitative research methods were employed. Quantitative data included, for example, information on river flow, water quality, economic activity, and demographic characteristics, with data manipulation and analysis performed using GIS and various statistical software packages. Qualitative approaches involved archival research and the analysis of recent policy documents, with a database package used to organise information collected. Where possible and appropriate, indicator values were compared to local threshold values, and an attempt was made to construct a trend (history) for the indicator.

Data acquisition and manipulation was a lengthy process for some indicators because data were not originally collected for the purpose of sustainability assessment. For example, the analysis of environmental monitoring data required intensive use of computer models for the statistical treatment of results. Also, economic and demographic data needed to be converted to comparable units, scales and time series. A common problem was the distribution of data necessary for one indicator between a number of different organisations. Other problems included: data not being readily available at the catchment scale; incompatible time series for parameters included in the same indicator; a lack of long term monitoring/records; and, interruptions to data records or changes in data recording methods. In some instances, therefore, it was not possible to obtain sufficient or otherwise satisfactory data to enable the use of every indicator expression in Table 1. Proxy expressions were used in these cases, as explained below, relating to water use efficiency, sector productivity and water-related well-being.

2.3. Initial evaluation of the framework

Following data analysis, indicator findings were collated for each catchment and used as the basis for a further series of interviews with water resource experts and local water management professionals in Scotland and Brazil. Interviewees included a number of individuals who had previously been involved in refining the indicator framework (Table 2). The interviews were semi-structured, with participants asked a sequence of questions designed to provide an initial evaluation of the framework. In particular, information was sought to understand if and how the indicator framework might aid in better understanding, and responding to, specific catchment/water management issues. A summary table of indicator findings was used with each interviewee in order to inform the discussion of the framework. All interviews were transcribed, and analysis was based on identifying similar answer categories from transcripts to highlight commonalities and divergences of opinion.

3. Results

The following paragraphs outline the results for the Dee and the Sinos catchments together to illustrate the potential of the framework to capture key sustainability issues in different national and local circumstances. While the results of both catchments are discussed in the text, only one graphic or figure is presented to illustrate the development and application of the indicator framework. Where data availability allowed, an historical trend in values is presented for those indicators selected.

3.1. Environmental Dimension Indicators (water quality, water quantity and system resilience)

The calculation of the water quality indicator followed the local methodology adopted in each country for river quality classification. The situation for the Dee (not shown) was found to be encouraging, with all stretches classified as within the top quality category (class A1) for the period 1980-2001. A much less favourable picture emerged for the Sinos, however (Figure 1). Based on coliform concentrations, dissolved oxygen and BOD, almost the entire river was classed in the lowest quality category (class 4) for the period that data could be gathered (1990-2002). The results indicate that the water quality situation for the Sinos is very serious and has remained so for a long period of time. Current data suggest at least no further deterioration of the water quality condition in the Sinos, but such stable trend by no means minimise the challenge represented by water pollution for the more sustainable management of the catchment.

A contrast between the two catchments also emerged with reference to the maintenance of adequate water flows. For the Dee (not shown), average abstraction (between 1972-2001) was only some 11.7% of low flows (Q_{95}) during the dry season (Jun-Aug), well below the 25% abstraction threshold suggested for the United Kingdom (UKTAG, 2004). This can be taken as indicative of a sustainable situation. The same threshold (25% of Q_{95}) was also applied to the Sinos to compare water abstraction in 1996, the only year with available data, with the projected figures of demand in 2007 (cf. MAGNA, 1996). An allowance made for inter-basin water transfer into the upper Sinos for electricity generation, as requested by the indicator expression. The increase in the indicator results between 1996 and 2007 (from 0.23 to 0.27) suggests a trend of deteriorating water quantity condition in the Sinos (Table 5).

Regarding system stability, findings for the Sinos for 1973-2001 (not shown) showed wetter catchment conditions with generally larger and more variable (average) flows (likely to reflect changes in soil use due to deforestation and urbanisation). A similar reduction in stability was evident for the Dee (Figure 2) between 1972 and 2001. This graph is corroborated by the related technical literature, which argues that the flows of the River Dee are becoming more variable in the last few years due not only to increased floods, but also increased periods of low flows. Findings for this indicator suggest that hydrological regime is turning more variable in the both catchments, which has the potential to distabilise ecological features if the level of disturbance goes beyond the point of recovery (further field studies are required to assess the impact of hydrological changes on local biological communities)..

3.2. Economic Dimension Indicators (water use efficiency, user sector productivity and institutional preparedness)

Due to data shortage, a proxy indicator was used to give an indirect assessment of water use efficiency for the Dee. The indicator expression was replaced by a proxy formulation, which addressed regional trends of water use and economic activity for the north of Scotland between 1998 and 2002. Results (not shown) suggest that regional metered demand tended towards higher productivity (i.e. output per unit of water used), indicative of an improving sustainability situation. For the Sinos, data for water use and economic output were available at the catchment level, but only for the year 1996 (providing a ratio of 15,681 m^3 of water per US$ million of economic output). Clearly, nothing can be inferred from this individual finding in terms of a sustainability trend, but the indicator value may now be used as a baseline for any future assessment of water use efficiency for the Sinos catchment.

As with water use efficiency, insufficient data forced the adoption of a proxy of the fifth indicator (user sector productivity). In the case of the Dee, it was tried to related user sector productivity at the regional scale (north of Scotland), as a proxy of the indicator initially proposed. Results demonstrate that output remained practically constant between 1996 and 2000 for the majority of user sectors (in terms of Gross Value Added; i.e. GDP as factor cost in current prices). However, there were no data available to relate water demand with the economic performance of those sectors and, therefore, it was not possible to use even a proxy measure of this indicator for the Dee catchment. For the Sinos catchment, agriculture and industry were the only two sectors with data available, but only for the year 1996. In order to give some indication of sectoral water use efficiency for those two user sectors, a proxy of the proposed indicator was adopted: the ratio between water use and economic output (Table 6). Based on those results, it can be said that industrial uses of water demonstrated a more efficient use of water per unit of economic output.

The indicator of institutional preparedness provides the assessment of socioeconomic issues related to allocation of water resources, regulatory framework and enforcement capacity (note that this is a cross-cutting indicator between the economic and social dimensions of sustainability that for convenience was placed under the economic heading). In the Sinos, the indicator identified the pioneering institutional mobilisation in the catchment, where a river catchment committee (Comitesinos) was founded in 1988. However, other aspects included in this indicator formulation (not shown) made evident the difficulties of translating formal institutional arrangements into gains in terms of sustainable water resource management. The main obstacle for issuing licences and collecting charges is the absence of an executive agency, as defined by the legislation. The postponement of the establishment of this executive agency is a problem that has remained unsolved for a series of government cabinets. For the Dee catchment, there is not yet a comprehensive, systematic mechanism to deal with demands and conflicts over water quantity and quality (Table 7). Nonetheless, the indicator results highlighted some recent achievements towards water sustainability in the Dee, as the Dee Catchment Management Plan established in 1999 with the purpose of generating partnerships and promoting integrated catchment management. The experience up till now demonstrates the need to operate at a catchment scale for the establishment of a shared, long-term view of water sustainability.

3.3. Social Dimension Indicators (equitable water services, water-related well-being and public participation)

The results of the equitable water services indicator for the Sinos (not shown) showed an improvement in the coverage of water supply services from some 92% in 1991 to 97% in 2000. It is also worth noting that the public water supply situation in the Sinos catchment is better than the national average, adding weight to a tentative conclusion that this aspect of water resource management appears relatively favourable in sustainability terms. For the Dee, a very similar proportion (97.5%) of the catchment population was served (2000 data) by public water supply (Table 8). This proportion is, however, slightly below the Scottish average of 98.5% (WCC, 2003) and this may, therefore, be an issue to be addressed by policy makers. A relatively high proportion of the population within the Dee catchment resides in comparatively remote, upland areas in scattered communities, and improving on the current situation may prove difficult.

Inadequate data meant that proxy indicators of water-related well-being had to be used for both catchments. For the Sinos, the UN-based 'Municipal Human Development Index' (MHDI) was calculated at the catchment scale. Findings (not shown) indicated improving well-being for the population of the catchment, with an increase in Index value from 0.75 in 1991 to 0.81 in 2000 (last year with data available). For the Dee, the UK-based Index of Multiple Deprivation (SDRC, 2003) was calculated at the catchment scale. In his case, however, the Index could only be calculated for the year 2001, and so a comparison was made between the Dee catchment and other areas in Scotland (Table 9). The catchment score (801) compares favourably with other Scottish locations.

With reference to the final indicator, public participation, findings for the Dee (not shown) suggest that participatory management of water resources at the catchment scale still presents significant challenges for governmental and non-governmental organisations. The predominant form of public participation in the Dee catchment has been through consultation documents and open public meetings. In the sustainability context, we suggest that this has been insufficient to allow full and active participation in decision making. By contrast, after more than 15 years of activity, the Comitesinos (river catchment committee) for the Sinos would appear to have been relatively successful as a forum for discussion and conflict resolution (Table 10), although not without its problems, such as uneven engagement between water sectors, lack of legitimacy of some representatives and a need for capacity building among participants. This indicates the challenge to improve and consolidate channels of public participation and cooperation between water stakeholders and stakeholders and the environmental regulators. The implementation of new water legislation both in Scotland and in Brazil is likely to pose further demands on the catchment committee as the legitimate channel of public negotiation and consensus building.

4. Discussion

The results presented above are summarised in Table 11, which schematically compares the interpretation of the indicator results of both catchments. Difficulties associated with data acquisition and manipulation notwithstanding (we return to this issue below), the indicator framework would appear to have the capacity for application in contrasting national and local situations, helping to identify for policy makers and water resource managers priority issues that may require particular focus.

For the Dee, for example, where environmental and social conditions appear generally satisfactory and major water demand/efficiency issues appear not to threaten sustainability of supply, effort might be focused on building institutional preparedness and strengthening public participation in decision making. The latter is still a relatively new phenomenon, and there is no consistent or permanent form of participatory management in the catchment. The situation in the Sinos catchment appears much more challenging, with more immediate and significant threats to sustainability. Persistent pollution, aggravated by increasing water abstraction, is clearly a major problem, particularly in the lower sections of the river where most of the abstraction is concentrated. If river flows continue to become more variable (perhaps also an issue for the Dee), then this may pose additional demands on the management of water quality and quantity, as system resilience declines. The expansion of sanitation services and associated enhancement of water-related well-being also remains one of the most serious water management issues in the Sinos catchment. Ironically, it may be partly due to the severity of the water management challenges facing the Sinos that public participation has become a strong, positive feature of catchment management, with, for example, direct public involvement in the classification of water bodies and the activities of the Comitesinos.

The indicator framework and findings were the subject of interviews with local water management professionals and water resource experts. There was general agreement that the indicators were valuable in describing the sustainability conditions within the catchments, or, at least, provided an overview that demonstrated deficiencies and gains in working towards the sustainable development of water resources. The attempt to integrate environmental, economic and social dimensions of sustainability into a single framework was welcomed, with the point repeatedly made by interviewees that traditional approaches to the appraisal of water resources by the scientific community do not adequately link hydrological management with socio-economic demands. Other aspects of the framework that generally attracted favourable comment were the use of a relatively small, hence manageable, number of focused indicators, and flexibility in terms of allowing the incorporation of local data and thresholds.

It is also important, however, to acknowledge conceptual issues and practical limitations that emerged in constructing and applying the framework. Many interviewees highlighted the complexity and subjectivity involved in formulating a framework of indicators, particularly one which sought comprehensiveness in addressing and connecting socio-economic as well as environmental sustainability dimensions. A perception (and criticism that can be made of all indicator frameworks) amongst some interviewees was that the framework represented a considerable over-simplification of real world processes. This should, however, be seen in the context of general agreement that a relatively small number of indicators makes the sustainability assessment of water resource management more manageable. Indeed, problems with data acquisition and manipulation would have increased with a larger number of indicators. Arguably, such problems were the most challenging feature of applying the framework. In some cases, suitable data were unavailable requiring the use of proxy indicator expressions. More commonly, very considerable effort was required to obtain, collate and manipulate (particularly socio-economic) data for the catchment scale. Interviewees generally recognised the limitations imposed on the development and evaluation of suitable water management indicator frameworks by poor or restricted data availability, and some pointed to recent changes that might improve data availability. In Scotland, for example, compliance with the EU Water Framework Directive should result in more and better water use and hydrological monitoring data, while acquiring other data held by public agencies should now be easier with the recent introduction of the ‘Freedom of Information (Scotland) Act’.

Certainly, there is much scope for further research on water resource management indicators. As well as formulating alternative frameworks using different approaches at the catchment scale, perhaps also incorporating new individual indicators that further connect socio-economic drivers of change with environmental parameters, future research might also consider spatial variation at the sub-catchment scale. Indeed, a tiered framework with nested indicator sets at sub-catchment, catchment and supra-catchment scales may even eventually be possible, allowing different types of policy and management issue to be addressed at the most appropriate scale.

5. Conclusions

Framework of indicators, when properly developed, can be a useful tool to inform water resource managers of progress towards the more sustainable use of freshwater resources at the catchment scale. As exemplified in this paper, there are important challenges related to the development and validation of indicators, for instance integration of data and interpretation of results. Sustainability indicators should be seen as a ‘learning process’ and the outcomes should be used with caution. Despite various difficulties, the adoption of water sustainability indicators can inform the assessment of sustainability condition and future trends. Embedded within such frameworks should be indicators that address, even combine, environmental, economic and social aspects of sustainability allowing a more holistic appraisal of water management than has traditionally been the case. Research reported here suggests that it is possible to construct and apply such a framework using a relatively small and manageable number of indicators, although lack of suitable data required the use of proxy indicators for some parameters. Application of the framework identified areas of concern, and was broadly welcomed by water management professionals and water resource experts as a means of fostering understanding and action across key aspects of sustainability. Findings for the Dee catchment suggest that more effort might be focused on building institutional capacity, including public participation, for water resource management, while pollution and lack of access to public water supply appear to be much more serious issues in the Sinos catchment. Findings indicate that resilience to perturbation may be declining in both catchments. Lack of available data in appropriate forms provided, to some extent unanticipated, difficulties in applying the framework, and data availability remains a serious obstacle to the further development of holistic indicator frameworks, which indicates that the indicator framework need to be adaptable enough to cope with local institutional circumstances, data availability and management approaches. This said, more research is also required to better understand how different approaches to indicator development affect indicator selection, which can enormously benefit from a better dialogue between natural and social scientists, water users, environmental regulators and the public at large.

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